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A World Class Energy Efficient University Building by Danish 2020 Standards

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Abstract

The paper provides an overview of the OU44 building as a highly energy efficient teaching building at the University of Southern Denmark in Odense. The 8500m^2 3-storey building was designed to meet the 2020 buildings energy class consuming only 42 kWh/m^2, marking it at the top of energy efficient public buildings in the world. As a case study under the international research project COORDICY, the goal of OU44 is to function as a living lab building for research in energy informatics and occupancy behavior, aiming to improve the energy efficiency of public buildings, with full capability to monitor, manage and control the building operation. The building is equipped with energy efficient technologies including, ventilation units with heat recovery, LED lights, underfloor heating, PV modules, in addition to heating, lighting and electricity consumption sub-meters, and temperature, humidity, CO_2, Lux and PIR sensors on the room level. Using collected data, the building performance in the first year of operation is reported in this paper, showing that the building is in agreement with the expected design numbers consuming about 41.45 kWh/m^2. In addition, a modeling and simulation methodology is developed and implemented in the OU44 Building case to simulate the building energy performance. Employing a weather file updated for local conditions and a camera-based generated occupancy schedule, the preliminary building performance simulation results are presented and compared to the actual data. It was shown that the dynamic EnergyPlus model allows better prediction of the building energy performance compared to the Danish building certification tool BE10. As a living lab, the OU44 energy model developed is intended to be used for continuous monitoring and optimizing the performance on a daily basis to ensure that the building is performing as expected, forming a backbone for the fault detection and diagnostics work within the COORDICY project.

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Keywords: Building energy modeling; performance simulation; OU44 Building; occupancy counts; energy monitoring and optimization.

1. Introduction

Improving energy performance of buildings is vital to reduce energy consumption and attain energy supply security. In its 2050 holistic strategy to become free of fossil fuels in the energy sector, the Danish government has highlighted the importance of improving the energy performance of the building sector and implementing cost-effective measures to reduce the consumption to achieve the ambitious 2050 goals. The Danish building directive calls for 75% reduction in energy consumption for new buildings by 2020 compared to 2006 levels. The Danish Building Regulation BR10 came into action on the 1st of January 2011 [1], with a 25% improvement on the overall building energy performance and insulation requirements for components and elements compared to BR08. The BR10 regulation includes also a low energy building class labelled as ‘class 2015’, with another more strict building class 2020, which will be mandatory in the near future, demanding additional requirements related to building energy performance and documentation. A non-residential building is labelled as a 2020 building if the annual overall energy demand, covering heat loss, ventilation, cooling, domestic hot water and lighting does not exceed 25 kWh/m^2 of the heated floor area in addition to supplementary allowances. Presenting the design and energy performance of highly efficient buildings is important to inspire the creation of more energy efficient buildings with better indoor environment. This work presents an overview of one of the first 2020 public buildings in Denmark, OU44 Teaching Building at the University of Southern Denmark. The building is unique in its design, construction process, technologies and systems and energy performance. An overall description of the building is provided in this paper along with reporting the energy performance in the first year of operation. In order to monitor and control the energy performance of the building and to ensure a proper operation of all the subsystems, a holistic building energy model is developed and the preliminary simulation results are reported, employing an updated weather file and improved occupancy schedules based on camera counts. The work is carried out under the COORDICY project, a strategic interdisciplinary research project with collaboration between 20 industrial and academic partners in Denmark and USA, aiming to reduce energy performance gap in new energy-efficient public and commercial buildings and improve the energy-performance of existing buildings. Aiming to establish the new building as a highly advanced living energy lab, the OU44 energy model developed will be used for monitoring and optimizing the energy performance on a daily basis to ensure a proper operation of the building, forming a base for the fault detection and diagnostics work within the COORDICY project.

2. OU44 Building

In Fall 2015, a new teaching building, OU44 Building shown in Fig. 1, was opened for students and lecturers at the University of Southern Denmark, Odense Campus. The 8500m^2 Building has three floors and a basement, comprising mainly classrooms, offices and meeting rooms with a capacity to accommodate around 1350 people. The construction contract demanded that the building comply with the Building class 2015. But due to careful planning and well-organized construction process, the building was found to comply with the 2020 highest energy class in Denmark. This high energy efficient performance and good indoor environment was achieved with no delays in the design and construction process and with no additional costs. This ranks the OU44 building among the top energy efficient buildings on an international level with the aim of transforming the building into a living lab with energy efficient operation and advanced systems control and optimization. Before delivery, 11 technical performance tests were implemented in the building to assess the overall operation and performance of various energy systems and installations including electricity, ventilation, heating and lighting. The aim of the tests is to deliver a highly energy efficient building which function properly from day one. District heating is mainly used to fulfil the heating demands with additional small-scale electrical heating backup where heating radiators are equipped with mechanical valves. Four balanced ventilation units with heat recovery wheels and pre-heating coils are spread along the building providing the required fresh air with air handling units nominal capacity of 35000 m^3/h. A 12 kW PV solar system is implemented on the building roof for electricity production. In addition to its highly energy efficient supply systems, the building is equipped with a large number of sensors and meters on different levels with a high capability to monitor and control the overall building operation as shown in Fig. 1. Certain rooms, labelled as trial zones, are equipped with additional sub-meters for plug loads, lighting and radiator heating with the aim to use these zones for more in depth energy control and management. Above all, the building is equipped with a Schneider Electric building management system (BMS) allowing control and optimization of the systems operation on the rooms and the whole building levels.

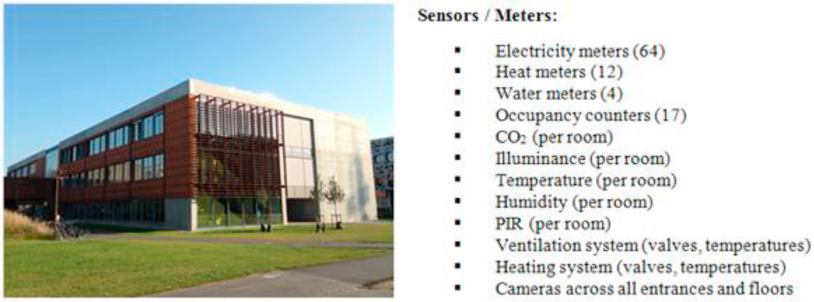

Fig. 1. OU44 Building and the corresponding embedded sensors and meters.

3. Reported OU44 Building Operation

BE10 is the official building performance certification tool for buildings in Denmark based on the Danish Building Regulations. The tool provides a static energy performance prediction on a monthly basis, treating the building as one whole entity, with major assumptions regarding the building subsystems operation, and without taking into account occupancy behavior and weather conditions. For the OU44 building to comply with the 2020 building energy class, the maximum allowed primary energy consumption is 42 kWh/m^2, taking into account a supplement due to special conditions specified in the standards. Fig. 2 presents an overview of the holistic building energy performance throughout a complete year (2016), based on the data collected by various meters all around the building. It is shown that the building is complying with the 2020 energy class standards consuming only 41.45 kWh/m^2 for lighting, ventilation and heating, and taking into account the PV electricity generation. However, as Fig. 2 shows, there is a large gap between the BE10 design numbers and the actual data in terms of the individual subsystems operation; lighting, ventilation and heating systems. Obviously, a major reason for such a gap is the major assumptions adopted by the BE10 tool, especially neglecting the effect of occupancy and weather conditions. To overcome this, it was decided to develop and implement a dynamic holistic energy model for the building to provide a more precise and detailed prediction, monitoring and optimization of the energy performance through developing an Online Energy Performance Monitoring Tool. The work is a part of the COORDICY Project [2] and the following sections provide an overview of the adopted methodology and the preliminary results attained.

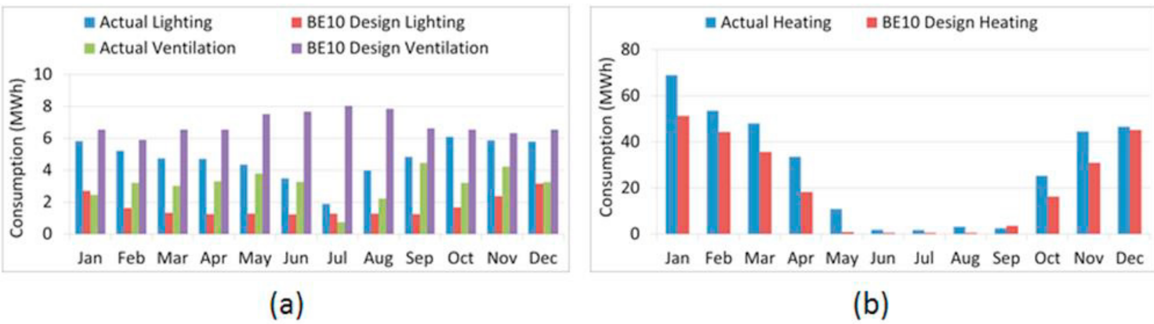

Fig. 2. BE10 Design vs Actual energy consumption for (a) Ventilation and Lighting; (b) Heating.

4. Modeling and Simulation Methodology

As a basis for the modeling and simulation methodology, the building performance simulation tool EnergyPlus is used in this work to model and simulate the holistic energy performance of the OU44 Building. EnergyPlus modeling and simulation procedure is based on solving equations of energy conservation using the nodal approach, and employing a well-established and validated simulation engine. In modeling the building, EnergyPlus takes into account various characteristics and specifications including building orientation and geometry, energy systems, building services, thermal envelope, constructions, occupancy behavior and the location weather conditions. To aid the energy modeling process, two supporting tools are used besides EnergyPlus, OpenStudio and Sketchup Pro. Sketchup Pro is a 3D modeling software used to draw spaces and create 3D models of buildings with a high level of detail. It is used in this work to read the OU44 3D model from the previously developed Building Information Model (BIM), providing an accurate representation for the building geometry and orientation with precise allocation of rooms and spaces. In addition, OpenStudio is an energy modeling tool establishing the link between the 3D model developed in Sketchup and the EnergyPlus simulation engine. It provides a more flexible and user-friendly interface to define the detailed building specifications compared to the default EnergyPlus interface. OpenStudio is used in this work to build the OU44 building energy model and define the detailed characteristics mentioned earlier spanning from the weather conditions to the thermal envelope and occupancy behavior. A detailed description of the modeling and simulation methodology is presented by Jradi et al. [3], comprising the following steps: 1) Collecting building information and data available; 2) Reading the building 3D model from the BIM delivered by the consultant company; 3) Defining the detailed energy model in OpenStudio; 4) Simulating the building energy performance employing a weather file and occupancy schedule; and 5) Reporting the dynamic energy performance. This methodology was implemented to develop the detailed dynamic energy performance model of the OU44 Building. Fig. 3 presents the 3D Sketchup model for OU44 Building read from the BIM, with modifications to ensure a proper representation of all building spaces. Information regarding the building thermal envelope, constructions, loads, energy systems operation, schedules and weather conditions were defined in OpenStudio to develop the OU44 Building energy model.

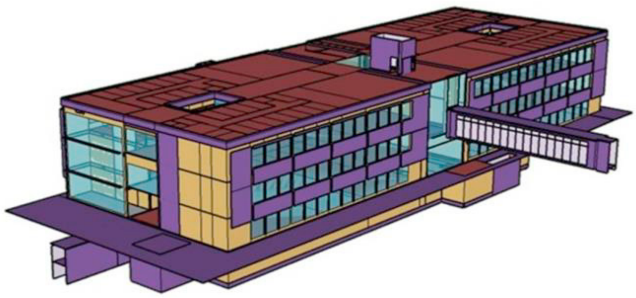

Fig. 3. OU44 3D Sketchup model

5. Occupancy Counts and Schedules Generation

The estimation of the number of occupants in a building provides an essential bedrock for understanding, estimating and optimizing both energy consumption and occupancy comfort amongst other energy drivers. Amongst all sensor modalities listed in literatures for count estimation, both 3D stereovision and thermal camera provide a better alternative with minimal estimation errors. However the high cost of thermal cameras and the decreasing cost of 3D stereovision camera makes the 3D cameras a better trade-off for deployment. In OU44 building, 17 stereovision cameras were deployed at the entrances of 2 classrooms, 2 rooms, all passages to each floor and all entrances to the building. Fig. 4 (a) and 4 (b) show the 3D stereovision camera unit and a sample image from the camera unit. It should be noted that all video processing used for occupancy count are processed real-time on the camera unit itself and only occupancy counts are reported from the camera units, enabling occupants privacy rights protection. Regarding the counting methodology, the 3D camera-based provides occupancy counts with low error estimates. They are mostly accurate in the short term and may accumulate error over a long period of time due to occlusion, pixel intensity fluctuation and poor lighting conditions, yielding false positive and negative counts. To correct such erroneous counts, first occupancy count problems are formulated by obtaining all transition events from all count-lines in the building to compute the total transition and cumulative count at each timestamp for the building. Secondly, the computed transition and cumulative counts are corrected using a three-step probabilistic correction method (PLCount) [4]. Given the corrected occupancy counts, the weekly profiles for each month are generated by computing the average of obtained occupancy counts of each unique day of a week in a month. The derived averages are propagated for all days in the month to form a week profile for that month. This weekly profile is adopted as the de facto occupancy schedule for simulating energy consumption. In this study, corrected occupancy data from September to December, 2016 were obtained to produce weekly profiles for these respective months as previously specified. Also, given the hypotheses that educational activities are the major driving factor behind occupancy variations in the weekly profiles and that similar educational activities are expected for the subsequent year (2017), the profiles generated for the aforementioned months in 2016 could be used as occupancy projections for the same months in the subsequent year (2017). The OccuRE framework [5] facilitates the occupancy profile generation process through providing flexible and robust platform allowing seamless data queries of aggregated occupancy counts, a strategy reasoning module for selecting relevant deployed occupancy strategies at runtime, for instance PLCount for correcting summed occupancy counts and a REST API for direct integration of relevant occupancy strategies into building simulation programs. Fig. 5 presents a sample of a generated hourly occupancy schedule in the OU44 Building in the period from September to December 2016, based on the occupancy camera counts, showing a maximum of 935 people using the building at a time within that period.

(a) (b)

Fig. 4. (a) Camera unit; (b) Video capture from a camera unit.

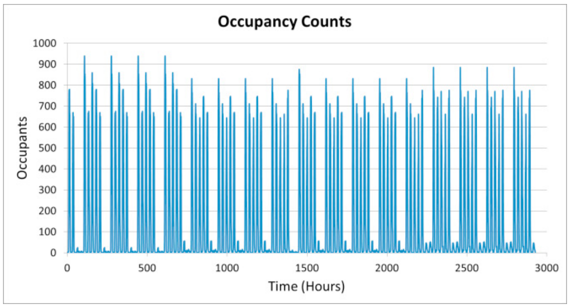

Fig. 5. A generated occupancy schedule from Sep. until Dec. 2016.

6. Online Energy Performance Monitoring Tool

The developed holistic EnergyPlus OU44 Building energy model will be used as a basis for online simulation, monitoring and optimization of the energy performance throughout a systematic fault detection and diagnostics process. The aim of this process is to ensure that the highly energy efficient building is operating as expected, and to interfere if any deviation in the performance is detected. An Online Energy Performance Monitoring Tool is developed where the holistic energy model will be running on a daily basis to simulate the OU44 Building's energy performance for the previous day taking into account accumulated weather data, occupancy schedules, and inputs from the building management system. The simulation results are reported and compared to the actual performance data gathered by energy meters at various levels of the building. By comparing the expected consumption with the meters actual data, it is possible to spot operation problems and faults, estimate the performance with respect to design goals and evaluate changes in building management, on the level of the whole building and other levels of aggregation. A Functional Mock-up Interface (FMI) standard is used to run and control the energy performance, and the EnergyPlus model is exported to a Functional Mock-up Unit (FMU) [6], a single self-contained file which can be run by any compatible FMI framework. Such frameworks expose input and output from the underlying model to the online tool, allowing mapping data streams from the storage system to model variables. As a result, the Energy Performance Monitoring Tool is completely model-agnostic, it just expects an FMU and two mappings (data stream ↦ input variable) and (output variable ↦ data stream). It is therefore easy to update a model to reflect changes in the building, deploy to another building or even switch to a different simulation engine.

7. EnergyPlus Holistic Model Preliminary Simulation Results

Implementing the energy modeling and simulation methodology described above, an overall dynamic energy model of the OU44 building is developed taking into account various building characteristics and specifications and employing the camera counts-based occupancy schedules and actual weather conditions. Fig. 6 presents the preliminary simulation results of the holistic OU44 building energy performance for the period from September to December 2016. Considering the energy performance of the building Heating, Lighting and Ventilation subsystems, it was found that the average energy performance gap BE10 vs actual meters data is a significant 55%, where this gap is reduced to only 11% in the case of EnergyPlus model data vs actual data. Thus, the dynamic EnergyPlus model allows better prediction of the overall building performance compared to the static BE10 tool. The results attained are satisfactory and the following step will be calibrating the model using actual collected data and technical information from the BMS. The calibrated model will then be running within the Online Energy Performance Monitoring Tool described above to allow daily energy performance simulation, monitoring and optimization, allowing building operation diagnostics and fault detection.

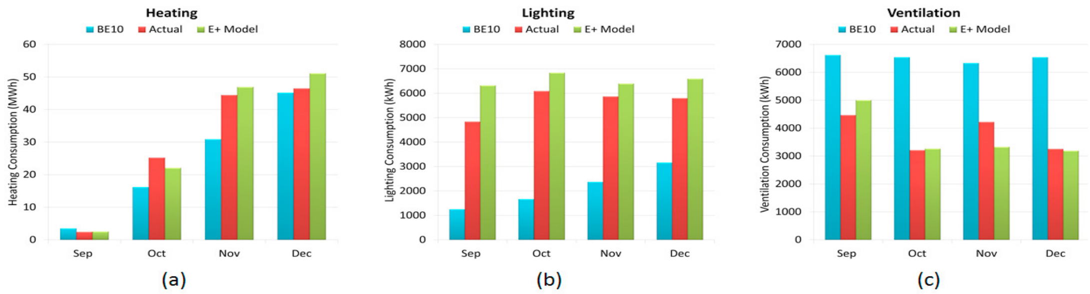

Fig. 6. Comparison between BE10 design numbers, actual data and E+ model simulations for (a) Heating; (b) Lighting; and (c) Ventilation.

8. Conclusion

A new teaching building, OU44 Building at the University of Southern Denmark, Odense Campus is investigated in this paper. An overall description of the building is provided along with reporting the energy performance in the first year of operation. It was shown that the building is complying with 2020 Danish energy class, but with major average gap of 55% in terms of the sub-systems performance, comparing BE10 design numbers to actual data. Thus, a holistic building energy model is developed and preliminary simulation results are reported employing refined weather conditions and occupancy schedules. The dynamic model reduces the energy performance gap compared to actual data to only 11%. Using an Online Energy Performance Monitoring Tool, the energy model will be employed to continuously monitor and optimize the building energy performance ensuring that it is performing as expected, aiming to establish the building as a living lab with efficient technologies and advanced operation strategies.

Acknowledgements

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